RCA
Solid State

Thyristors and Rectifiers

Application Note
AN-6286

Latching, Gate-Trigger Circuits Using Thyristors for Machine-Control Applications

by M. Kalfus

Electromechanical latching circuits used in mechanical processing equipment require large numbers of electromechanical devices; these devices generate line transients, periodically malfunction (mechanically), and ultimately fail as a result of contact erosion. In addition, they are sometimes noisy, and add to the already noise-polluted environment. This Note describes a variety of approaches to the development of a solid-state, latching gate drive for the control of ac loads; the solid-state device used is the thyristor. The solid-state circuits described below have fewer undesirable characteristics than the electromechanical devices and are smaller and lighter.

LATCHING GATE–TRIGGER CIRCUITS

In many applications, particularly industrial machine controls, a latching relay is often used to permit a system or subsystem to be activated by a momentary pulse from a control processor or hand actuator. A basic latching circuit using an electromechanical relay is shown in Fig. 1. S1 is momentarily closed to pull contacts A and B of relay K closed. Once contact A is closed, S1 may be opened. Relay K and the load will remain activated until S2 is momentarily opened either manually or by a machine mechanism which has completed its cycle of operation.

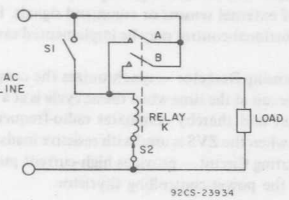

Fig. 1–Basic latching circuit using electromechanical relay.

A solid-state approach to this type of circuit, Fig. 2, offers reduced power consumption and a more compatible interface with process-control computers. In this simplified circuit, an external dc supply provides dc gate drive to power the COS/MOS flip-flop and collector current to drive the triac gate. Sufficient gate current must be available through R to meet the I+ and III+ gate requirements of the triac; an RsCs snubber network should be used when inductive loads are being controlled.

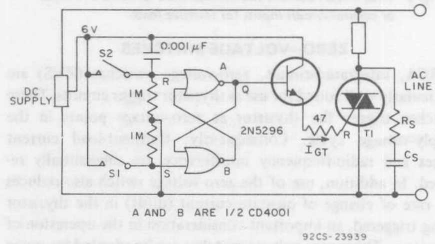

Fig. 2–Two dual-input NOR gates connected to form set-reset flip-flop.

In Fig. 2, two dual-input NOR gates, A and B, are connected to form a set-reset flip-flop which changes the state of the Q output when the voltage on either the S or the R input terminal is at a high level; the effective input will be that one last used. Power drain for the flip-flop circuit is negligible compared with that of the transistor driver stage supplying current to the triac gate. Power-supply requirements are, therefore, determined by the triac gating characteristics. The power requirements of the driver transistor are also a function of the triac gate characteristics. Since this circuit gates the triac in the dc mode, latching difficulties resulting from highly inductive load conditions or loads with very low power consumption can be eliminated. Except for the first half cycle of conduction, the triac will be in the on state continuously, and only an absolute minimum of radio-frequency interference will be generated on the subsequent half cycles. Of course, turn-off always occurs as the load current reduces to zero after gate drive has been removed.

Fig. 3 shows the waveforms of voltage and current in the triac circuit as a function of the control-circuit inputs for a resistive load. The low-level spike (2 to 4 volts) observed across the triac at the beginning of each half cycle occurs because of the operating characteristics of thyristors. A minimum voltage of 2 to 4 volts is generally necessary across a triac to initiate the regeneration process of the four-layer device, even in the presence of a dc gate bias.

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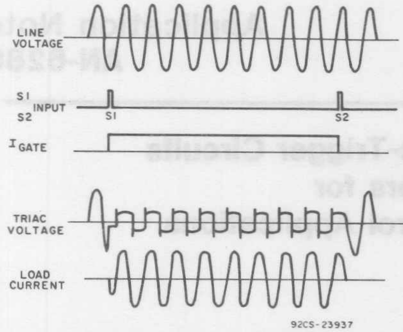


Fig. 3—Triac-circuit current and voltage waveforms as a function of control-circuit inputs for resistive load.

ZERO–VOLTAGE SWITCHES

RCA, integrated-circuit, zero-voltage switches (ZVS) are particularly well suited for use as thyristor trigger circuits. These switches trigger the thysistor at zero-voltage points in the supply-voltage cycle. Consequently, transient-load current surges and radio-frequency interference are substantially reduced. In addition, use of the zero-voltage switch also reduces the rate of change of on-state current (di/dt) in the thyristor being triggered, an important consideration in the operation of thyristors. These zero-voltage switches can be adapted for use in a variety of control functions by use of an internal differential comparator to detect the difference between two externally developed voltages. In addition, the availability of numerous terminal connections to internal circuit points greatly increases circuit flexibility and further expands the types of ac power-control applications to which these integrated circuits may be adapted. The excellent versatility of the zero-voltage switches makes them particularly useful in circuits designed to provide transient-free temperature control in self-cleaning ovens, to control gun-muzzle temperature in low-temperature environments, to provide sequential switching of heating elements in warm-air furnaces, to switch traffic-signal lights at street intersections, and to provide other diverse ac power-control functions.

Functional Description

RCA zero-voltage switches are multistage circuits that employ a diode limiter, a zero-crossing (threshold) detector, an on-off sensing amplifier (differential comparator), and a Darlington output driver (thyristor gating circuit) to provide the basic switching action. The dc operating voltages for these stages are provided by an internal power supply that has sufficient current capability to drive external circuit elements, such as transistors and other integrated circuits. An important feature of the zero-voltage switches is that the output trigger pulses can be applied directly to the gate of a triac or a silicon controlled rectifier (SCR). The CA3058 and CA3059 zero-voltage switches also feature an interlock (protection) circuit that inhibits the application of these output trigger pulses to the thyristor in the event that the external sensor is inadvertently opened or shorted. An external inhibit connection (terminal No. 1) is also available, so that an external signal can be used to inhibit the output drive. This feature is not included in the CA3079; otherwise, the three integrated-circuit zero-voltage switches, CA3058, CA3059, and CA3079, are electrically identical.

Overall Circuit Operation

Fig. 4 shows the interrelation of the functions in a zero-voltage switch, the external sensor, the thyristor being triggered, and the load elements, in an on/off type of ac power-control system. Fig. 5 shows the detailed circuit diagram for the integrated-circuit zero-voltage switches. Figs. 4 and 5 are representative of all three RCA zero-voltage switches, the CA3058, CA3059, and CA3079; the shaded areas in the figures indicate the circuitry that is not included in the CA3079.

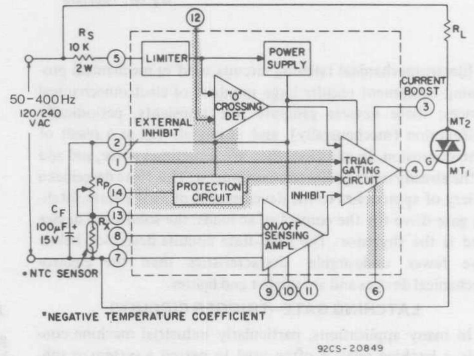


Fig. 4—Functional block diagram of CA3059 IC zero-voltage switch.

As shown in Fig. 4, each of the three zero-voltage switches incorporates four primary functions:

1. Limiter-Power Supply – permits operation directly from an ac line.
2. Differential On/Off Sensing Amplifier – tests the condition of external sensors or command signals. Hysteresis or proportional-control may be implemented easily in this section.
3. Zero-Crossing Detector – synchronizes the output pulses of the circuit at the time when the ac cycle is at a zero-voltage point and thereby eliminates radio-frequency interference when the ZVS is used with resistive loads.
4. Triac Gating Circuit – provides high-current pulses to the gate of the power-controlling thyristor.

In addition, the CA3058 and CA3059 are provided with the following important auxiliary features:

1. A built-in protection circuit that may beactuated to remove drive from the triac if the sensor becomes open or short-circuited.
2. An internal diode gate connected to terminal 1 that can be used to inhibit thyristor firing.

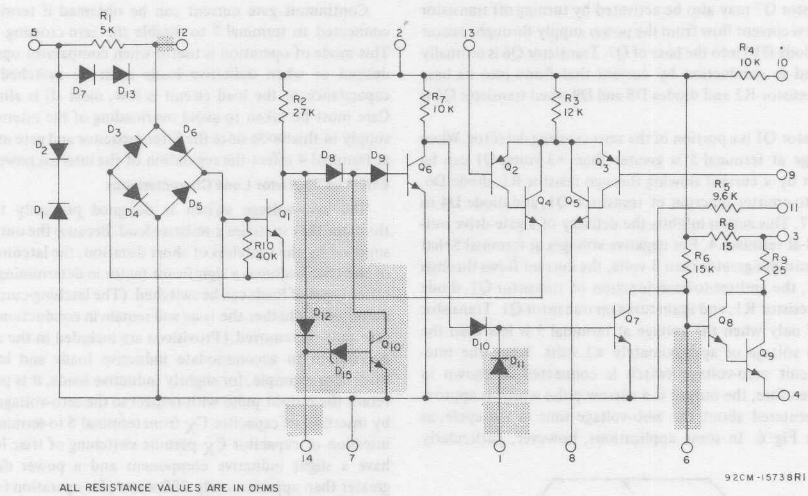


Fig. 5—Schematic diagram of CA3059 zero-voltage switch.

3. A means of attaining dc comparator operation by overriding the action of the zero-crossing detector. This override is accomplished by connecting terminal 12 to terminal 7. Gate current to the thyristor is continuous when terminal 13 is positive with respect to terminal 9, but is time-deviation limited and a function of the filter capacitor and the terminating impedance at terminal 4.

The limiter stage of the zero-voltage switch clips the incoming ac line voltage to approximately ±8 volts. This signal is then applied to the zero-voltage crossing detector, which generates an output pulse each time the line voltage passes through zero. The limiter output is also applied to a rectifying diode and an external capacitor, C_F, that compose the dc power supply. The power supply provides approximately 6 volts, as the V_{CC} supply, to the other stages of the zero-voltage switch. The on/off sensing amplifier is basically a differential comparator. The thyristor gating circuit is enabled when the line voltage is approximately zero volts, the sensing-amplifier output is high, the external voltage to terminal 1 is a logical zero, and, for the CA3058 and CA3059, the output of the fail-safe circuit is high. Under these conditions, the thyristor (triac or SCR) is triggered when the line voltage is essentially zero volts.

THYRISTOR TRIGGERING CIRCUITS

Diodes D1 and D2 in Fig. 5 form a symmetrical clamp that limits the voltages on the chip to ±8 volts; diodes D7 and D13 form a half-wave rectifier that develops a positive voltage on the external storage capacitor, C_F.

The output pulses used to trigger the power-switching thyristor are actually developed by the zero-crossing detector and the thyristor gating circuit. The zero-crossing detector consists of diodes D3 through D6, transistor Q1, and the associated resistors shown in Fig. 5. Transistors Q1 and Q6 through Q9 and the associated resistors compose the thyristor gating circuit and output driver. These circuits generate the output pulses when an ac input is at a zero-voltage point, so that rfi is virtually eliminated when the zero-voltage switch and thyristor are used with resistive loads.

The operation of the zero-crossing detector and thyristor gating circuit can be explained more easily if the on state (i.e., the operating state in which current is being delivered to the thyristor gate through terminal 4) is considered as the operating condition of the gating circuit. Other circuit elements in the zero-voltage switch inhibit the gating circuit unless certain conditions are met, as explained below.

In the on state of the thyristor gating circuit, transistors Q8 and Q9 are conducting, transistor Q7 is off, and transistor Q6 is on. Any action that turns on transistor Q7 removes the drive from transistor Q8 and thereby removes gate drive from the thyristor. Transistor Q7 may be turned on directly by application of a minimum of ±1.2 volts at 10 microamperes to the external-inhibit input terminal 1. (If a voltage of more than 1.5 volts is available, an external resistance must be added in series with terminal 1 to limit the current to 1 milliampere.) Diode D10 isolates the base of transistor Q7 from other signals when an external inhibit signal is applied, so that this signal is the highest priority command for normal operation. (Although grounding of terminal 6 creates a higher priority inhibit function, this leve is not compatible with normal DTL or TTL logic levels.)

Transistor Q7 may also be activated by turning off transistor Q6 to allow current flow from the power supply through resistor R7 and diode D10 into the base of Q7. Transistor Q6 is normally maintained in conduction by current that flows into its base through resistor R2 and diodes D8 and D9 when transistor Q1 is off.

Transistor Q1 is a portion of the zero-crossing detector. When the voltage at terminal 5 is greater than +3 volts, Q1 can be turned on by a current flowing through resistor R1, diode D6, the base-to-emitter junction of transistor Q1, and diode D4 to terminal 7. This action inhibits the delivery of a gate-drive output signal at terminal 4. For negative voltages at terminal 5 that have magnitudes greater than 3 volts, the current flows through diode D5, the emitter-to-base junction of transistor Q1, diode D3, and resistor R1, and again turns on transistor Q1. Transistor Q1 is off only when the voltage at terminal 5 is less than the threshold voltage of approximately ±2 volts. When the integrated-circuit zero-voltage switch is connected as shown in Fig. 4, therefore, the output is a narrow pulse which is approximately centered about the zero-voltage time in the cycle, as shown in Fig. 6. In some applications, however, particularly

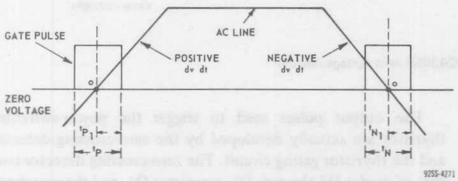
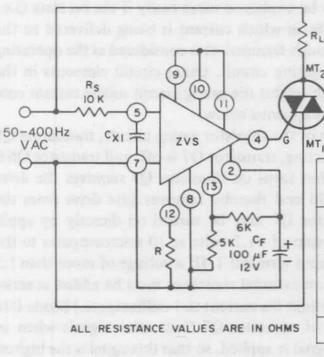


Fig. 6—Waveform showing output-pulse duration of zero-voltage switch.

those that use either slightly inductive or low-power loads, the thyristor load current does not reach the latching-current value* by the end of this pulse. An external capacitor, C_X, connected between terminal 5 and 7, as shown in Fig. 7, can be used to delay the pulse to accommodate such loads.



V_{AL} (V)	R_S	W_{RS} (W)
24	2	0.5
120	10	2
208/230	20	4
277	25	5
380	35	7

Fig. 7—Use of capacitor between terminals 5 and 7 to delay output pulse of zero-voltage switch.

Continuous gate current can be obtained if terminal 12 is connected to terminal 7 to disable the zero-crossing detector. This mode of operation is useful when comparator operation is desired or when inductive loads must be switched. (If the capacitance in the load circuit is low, most rfi is eliminated.) Care must be taken to avoid overloading of the internal power supply in this mode since the filter capacitor and gate impedance at terminal 4 affect the regulation of the internal power supply.

Effect of Thyristor Load Characteristics

The zero-voltage switch is designed primarily to gate a thyristor that switches a resistive load. Because the output pulse supplied by the switch is of short duration, the latching current of the triac becomes a significant factor in determining whether other types of loads can be switched. (The latching-current value determines whether the triac will remain in conduction after the gate pulse is removed.) Provisions are included in the zero-voltage switch to accommodate inductive loads and low-power loads. For example, for slightly inductive loads, it is possible to retard the output pulse with respect to the zero-voltage crossing by insertion of capacitor C_X from terminal 5 to terminal 7. The insertion of capacitor C_X permits switching of triac loads that have a slight inductive component and a power dissipation greater than approximately 200 watts (for operation from an ac line voltage of 240 volts rms). However, for loads less than 200 watts (for example, 70 watts), it is recommended that the user employ the T2300B† sensitive-gate triac with the zero-voltage switch because of the low latching-current requirement of this triac.

For loads, such as a solenoid valve, that have a low power factor, the user may operate the zero-voltage switch in the dc mode. In this mode, terminal 12 is connected to terminal 7, and the zero-crossing detector is inhibited. Whether a "high" or "low" voltage is produced at terminal 4 is then dependent only upon the state of the differential comparator within the integrated-circuit zero-voltage switch, and not upon the zero crossing of the incoming line voltage. Of course, in this mode of operation, the zero-voltage switch no longer operates as a zero-voltage switch. However, for many applications that involve the switching of low-current inductive loads, the amount of rfi generated can be tolerated.

SWITCHING OF INDUCTIVE LOADS

Gate drive must be applied to a thyristor in full-cycle operation soon after the current through the device reverses. When resistive loads are used, this reversal occurs as the line voltage reverses. With loads of other power factors, however, the current reversal occurs out of phase with the line voltage.

There are several methods for switching an inductive load at the proper time. If the power factor of the load is high (i.e., if the load is only slightly inductive), the pulse may be delayed by addition of a suitable capacitor between terminals 5 and 7, as described previously. For highly inductive loads, however, this method is not suitable, and different techniques must be used.

*The latching current is the minimum current required to sustain conduction immediately after the thyristor is switched from the off to the on state and the gate signal is removed.

†Formerly RCA-40526

If gate current is continuous, the triac will automatically reverse current. This mode of operation is established by connection of terminals 7 and 12. The zero-crossing detector is then disabled, so that gate-current is supplied to the triac whenever called for by the sensing amplifier. Although the rfi-eliminating function of the zero-voltage switch is inhibited when the zero-crossing detector is disabled, the problem is minimal if the load is highly inductive because the current in the load cannot change abruptly.

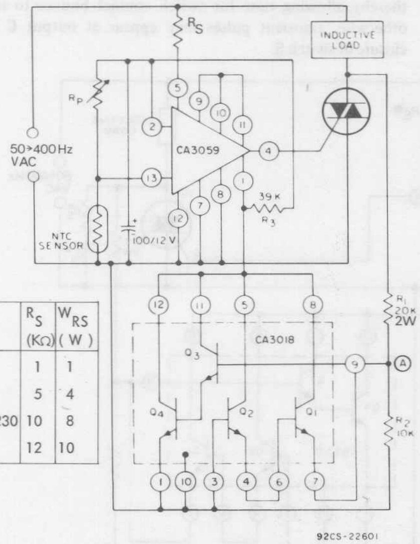
Circuits that use a sensitive-gate triac to shift the firing point of the power triac by approximately 90 degrees have been designed. If the primary load is inductive, this phase shift corresponds to firing at zero current in the load. However, changes in the power factor of the load or tolerances of components will cause errors in this firing time.

The circuit shown in Fig. 8 uses a CA3018 integrated-circuit transistor array to detect the absence of load current by sensing the voltage across the triac. The internal zero-crossing detector is disabled by connection of terminal 12 to terminal 7, and control of the output is made through the external inhibit input, terminal 1. The circuit permits an output only when the voltage at point A exceeds two V_{BE} drops, or 1.3 volts. When point A is positive, transistors Q3 and Q4 conduct and reduce the voltage at terminal 1 below the inhibit state. When A is negative, transistors Q1 and Q2 conduct. When the voltage at point A is less than ±1.3 volts, neither of the transistor pairs conduct; terminal 1 is then pulled positive by the current in resistor R3, and the output is inhibited.

The circuit shown in Fig. 8 forms a pulse of gate current, and can supply the high peak drive needed to power triacs, with a low average current drain on the internal supply. The gate pulse will always last just long enough to latch the thyristor, so that there is no problem with delaying the pulse to an optimum time. As in other circuits of this type, rfi results at initial turn-on if the load is not suitably inductive because the zero-crossing detector is disabled and initial turn-on occurs at random. The gate pulse is generated because the voltage at point A is less than 1.3 volts. When the thyristor is on, therefore, the output of the zero-voltage switch is inhibited, as described above. Resistor divider R1 and R2 should be selected to assure this condition. When the triac is on, the voltage at point A is approximately one-third of the instantaneous on-state voltage (V_T) of the thyristor. For most RCA thyristors, V_T (max) is less than 2 volts, and the divider shown is a conservative one. When the load current passes through zero, the triac commutates off. Because the circuit is still being driven by the line voltage, the current in the load attempts to reverse, and voltage increases rapidly across the "turned-off" triac. When this voltage exceeds 4 volts, one portion of the CA3018 conducts and removes the inhibit signal to permit application of gate drive. When the triac is turned on, the voltage across it drops, and the gate pulse ends. If the latching current has not been attained, another gate pulse forms, but with no discontinuity in the load current.

LATCHING CIRCUITS FOR RESISTIVE LOADS

When a resistive load, such as in an indicator lamp or heater element, is to be latched on, and the elimination of turn-on transients must be minimized, the circuit of Fig. 9 provides zero-voltage switching at the onset of turn on and at each half-cycle thereafter until switched off. In addition, this circuit provides dc power to the COS/MOS logic directly from the internal supply of the zero-voltage switch. The unused portion of the CD4001 can be applied to the other functions or to the same function if multiplicity of operation is required.



V_{AC} (V)	R_S (KΩ)	W_{RS} (W)
24	1	1
120	5	4
208/230	10	8
277	12	10

Fig. 8—Use of CA3058 or CA3059 together with CA3086 for switching inductive loads.

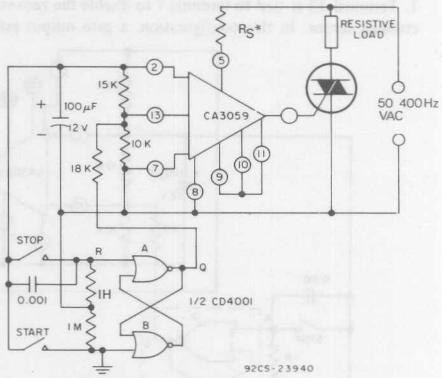


Fig. 9—Circuit that provides zero-voltage switching at the onset of turn-on and at each half cycle thereafter.

*See table Figure 7, Page 4

In the circuits of Figs. 2 and 9, the flip-flop logic function is implemented with low-power COS/MOS gates. However, in Fig. 9, the output, Q, controls the level of voltage at the input of a voltage comparator in the ZVS, terminal 13. Gate pulses generated at each zero-voltage crossing are generated from the ZVS at terminal 4 and drive the triac in the I+ and III+ gate modes. In Fig. 9 the triac is gated on at the beginning of each half cycle of ac line voltage, including the first half cycle, and rfi is virtually eliminated. However, because the gate pulses generated are very narrow (approximately 100 microseconds wide) at a time when line voltage is near zero (approximately 2.4 volts), this circuit is not recommended for use with highly inductive or low-power loads which prevent the minimum triac-latching current from flowing through the load circuit prior to the end of the gate pulse. The circuit of Fig. 10, a latching type circuit for electromechanical loads that uses the same basic logic as the circuit of Fig. 9, is suggested for the control of inductive loads by a triac.

LATCHING CIRCUITS FOR INDUCTIVE LOADS

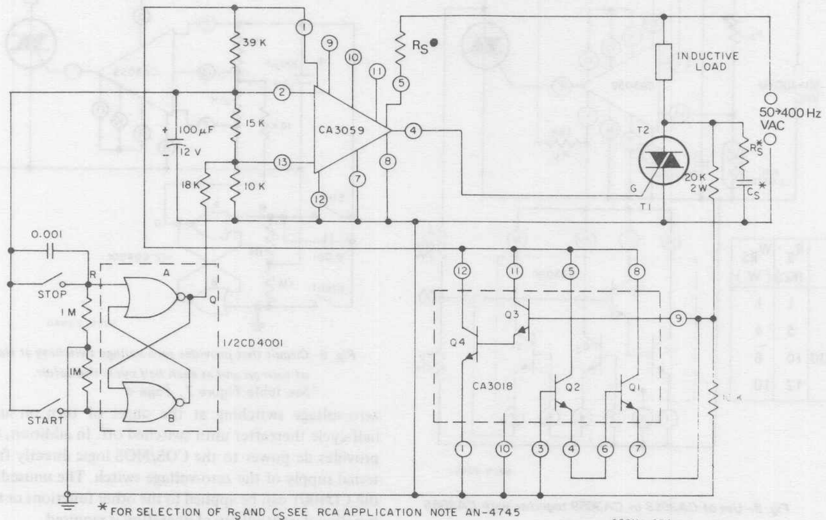
Fig. 10, a modification of the zero-voltage switch using a CA3018 transistor array, effectively converts the CA3059 into a zero load-current switch and provides a gate pulse long enough to assure that latching current is achieved. In this mode of operation the initial turn on can occur at random; however, as a result of the inductive nature of the load, rfi is usually minimal.

In Fig. 10, the CA3018 transistor array is used to sense the on state of the triac by monitoring the T1 to T2 voltage. Once the triac has latched on, the T1 to T2 voltage will be no greater than about 2.0 volts for any RCA triac operating within its ratings. The CA3018 interfaces with the ZVS switch at terminal 1. Terminal 12 is tied to terminal 7 to disable the zero-voltage crossing sensor. In this configuration, a gate output pulse at terminal 4 occurs when the following two conditions occur simultaneously; flip-flop output, Q, high, and triac T2 voltage greater than approximately 4 volts. As in the preceding circuits, dc supply voltage is available directly from the internal regulated supply of the ZVS.

An alternate logic function in some machine processes requires activation of the load after the start switch has been closed and opened; Fig. 11 is a typical electromechanical circuit which accomplishes this function. When switch S is moved to the B position, relay K is activated and latched on through the KB contacts. Load current is blocked by the open contact A at switch S; the contact remains open until switch S is released. Load current flows after switch S is released until the latched relay is de-energized by interrupting the current in the relay coil by opening switch R momentarily.

LATCHING CIRCUITS WITH HOLD-OFF FUNCTION

Fig. 12 shows a solid-state circuit whose function is identical with the circuit of Fig. 11. In Fig. 12, the ZVS is used as in Fig. 9; Fig. 2 or Fig. 10 may be modified similarly, as the only change required involves the COS/MOS logic circuitry. No additional components are necessary to accomplish this logic function. In Fig. 12, a third dual-input NOR gate (unused in the circuits previously described) holds the $\bar{Q}$ output of the flip-flop off as long as the set or start switch, S, remains closed because the A input to gate III is held high. The closure of S has also changed the state of $\bar{Q}$ to a low level. When S is released or opened, the A and B inputs of gate III are both low, and the output, C, goes high and enables the ZVS to generate gate pulses to the triac. Capacitor C1 serves to integrate the set- or start-voltage step, thereby allowing time for switch contact bounce to subside; otherwise, transient pulses may appear at output C during closure of switch S.



* FOR SELECTION OF R_S AND C_S SEE RCA APPLICATION NOTE AN-4745

● See table Figure 8, page 5

Fig. 10–A latching-type circuit for electromechanical loads.

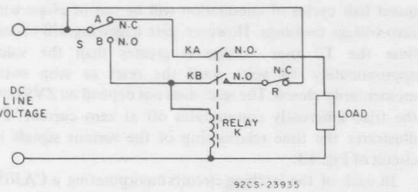


Fig. 11—Electromechanical circuit that activates the load after the start switch has been closed and opened.

The circuit in Fig. 10 may be unusable in some applications requiring very low turn-on transients. Turn-on in this circuit can occur anywhere within the first positive or negative half cycle and can cause a significant rate of change of current in the load, particularly if the load is resistive in nature. Once latch-up of the trigger circuit is complete, each half-cycle trigger will occur when approximately ±4 volts appear across the main terminals of the thyristor.

DELAYED LATCHING WITH ZERO-VOLTAGE SWITCHING

Fig. 13 is a latching circuit which switches the triac on at the first zero-voltage crossing following the initiation of the operating cycle. Thereafter, each gate pulse occurs as the triac voltage increases in magnitude to greater than 4 volts. This circuit utilizes the ZVS as a zero-voltage clock to initiate a change of the state of the flip-flop at a zero-voltage crossing when the S or start switch is closed. The CA3083, a 5-transistor array, serves the same function as the CA3018 in the previously described circuits. In addition, Q2 is used as a triac gate current driver in an emitter-follower fashion. Within 8.3 milliseconds after the start

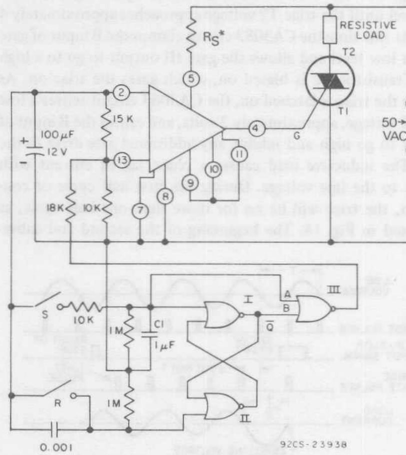


Fig. 12—Solid-state circuit that accomplishes the function of the electromechanical circuit of Fig. 11.
*See table Figure 7, page 4

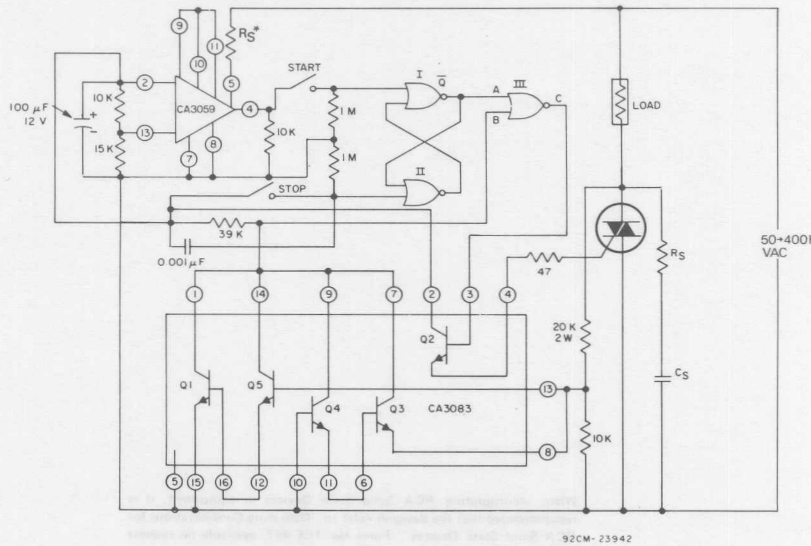


Fig. 13—Latching circuit that switches the triac on at the first zero-voltage crossing following initiation of the operating cycle.
*See table Figure 7, page 4

switch is momentarily depressed, a pulse from the ZVS will change the state of the flip-flop, causing $\overline{Q}$ (A input to gate III) to go low. This change occurs within 2.4 volts of the zero-voltage crossing. The CA3083 circuit holds the B input of gate III at a high level until the triac T2 voltage approaches approximately 4 volts. At this time the CA3083 circuit clamps the B input of gate III to a low level and allows the gate III output to go to a high level. Transistor Q2 is biased on, which gates the triac on. As soon as the triac is latched on, the CA3083 circuit senses a low triac T2 voltage, approximately 2 volts, and causes the B input of gate III to go high and inhibit any additional gate drive to the triac. The inductive load causes a phase lag of current with respect to the line voltage. During the first half cycle of conduction, the triac will be on for more than one half cycle, as illustrated in Fig. 14. The beginning of the second and subsequent half cycles of conduction will be out of phase with the zero-voltage crossings. However, gate triggering will occur each time the T2 triac voltage is greater than the value of approximately ±4 volts until the reset or stop switch is momentarily closed. The reset does not depend on ZVS pulses as the triac inherently commutates off at zero current. Fig. 14 illustrates the time relationship of the various signals in the circuit of Fig. 13.

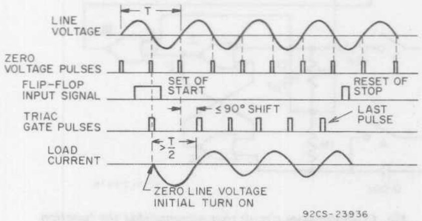


Fig. 14–Time relationship of various signals in the circuit of Fig. 13.

In each of the latching circuits incorporating a CA3059, an additional control input or feedback signal may be used to modulate a control function. One very common feedback function in machine controls is temperature. A thermistor may be substituted for one of the two resistors biasing terminal 13 of the zero-voltage switch, as shown in Fig. 4. This variable element will inhibit output pulses at terminal 4 whenever the voltage on terminal 13 is reduced below the voltage at terminal 9. This approach is not directly applicable to the circuit of Fig. 13; however, temperature feedback can be used to prevent initiation of a process control function with this circuit.

REFERENCE

"Features and Applications of RCA Integrated-Circuit Zero-Voltage Switches (CA3058, CA3059, CA3079)," A.C.N. Sheng, G. J. Granieri, J. Yellin, RCA Application Note ICAN-6182.